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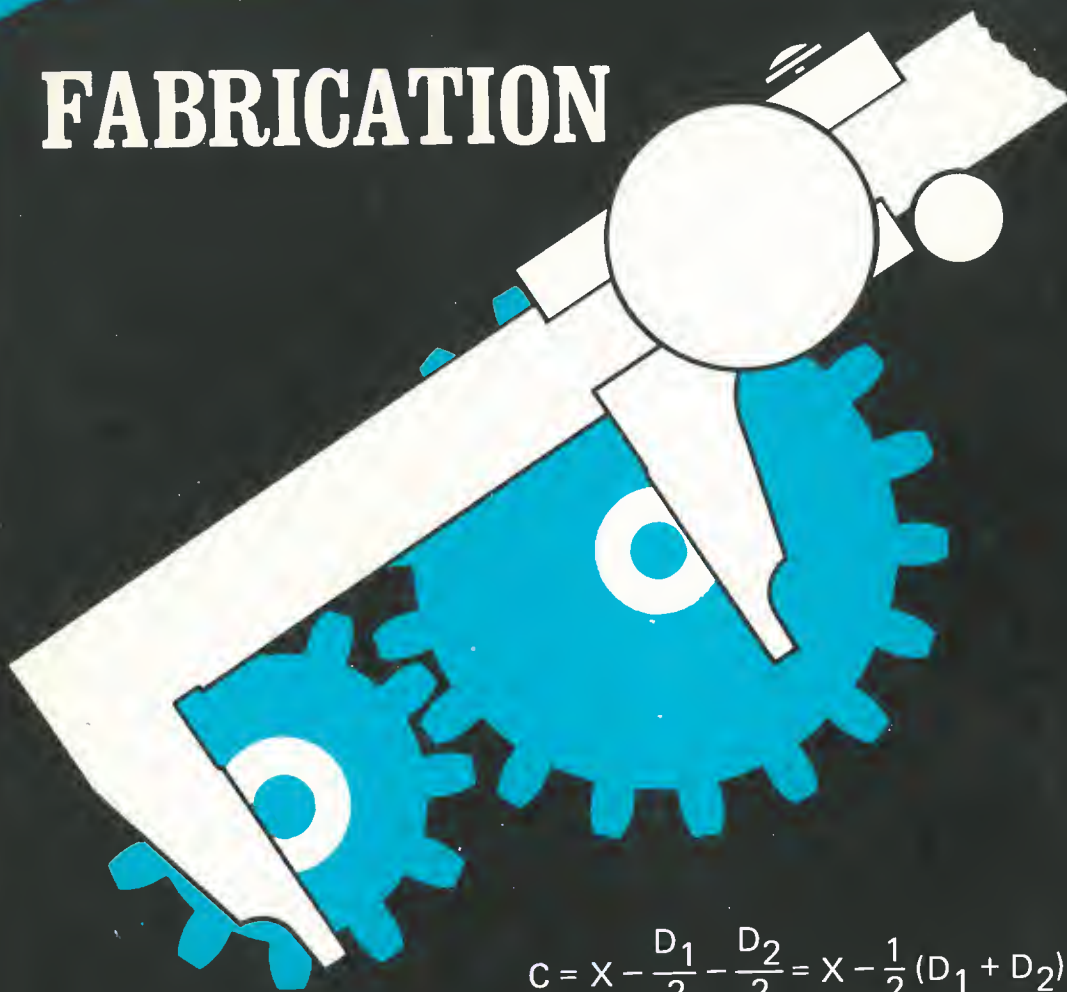


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**ELECTRO  
MECHANISMS**

# **FABRICATION**



$$C = X - \frac{D_1}{2} - \frac{D_2}{2} = X - \frac{1}{2}(D_1 + D_2)$$

**Electromechanical  
Technology Series**  
TERC EMT STAFF

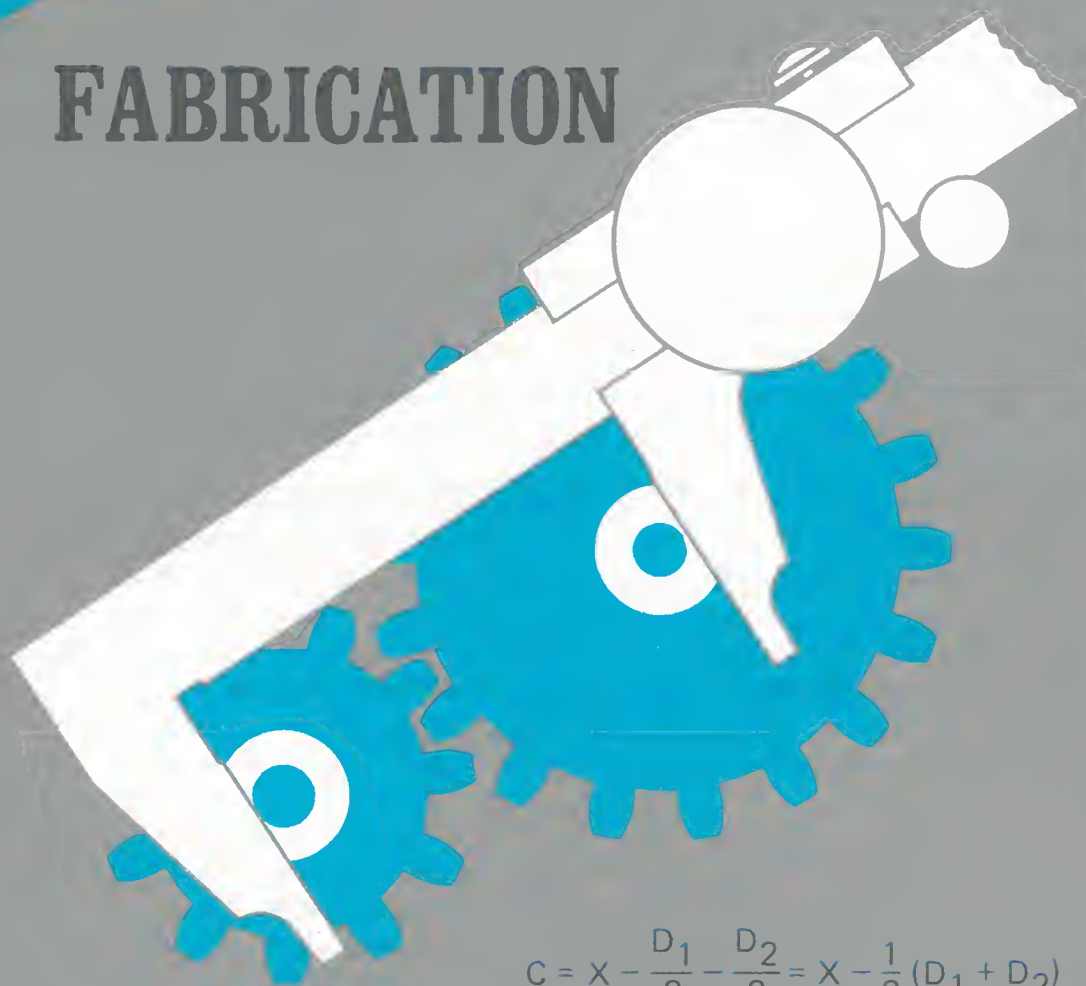


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K. PAUL



DELMAR PUBLISHERS, MOUNTAINVIEW AVENUE, ALBANY, NEW YORK 12205

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## Foreword

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The marriage of electronics and technology is creating new demands for technical personnel in today's industries. New occupations have emerged with combination skill requirements well beyond the capability of many technical specialists. Increasingly, technicians who work with systems and devices of many kinds — mechanical, hydraulic, pneumatic, thermal, and optical — must be competent also in electronics. This need for combination skills is especially significant for the youngster who is preparing for a career in industrial technology.

This manual is one of a series of closely related publications designed for students who want the broadest possible introduction to technical occupations. The most effective use of these manuals is as combination textbook-laboratory guides for a full-time, post-secondary school study program that provides parallel and concurrent courses in electronics, mechanics, physics, mathematics, technical writing, and electromechanical applications.

A unique feature of the manuals in this series is the close correlation of technical laboratory study with mathematics and physics concepts. Each topic is studied by use of practical examples using modern industrial applications. The reinforcement obtained from multiple applications of the concepts has been shown to be extremely effective, especially for students with widely diverse educational backgrounds. Experience has shown that typical junior college or technical school students can make satisfactory progress in a well-coordinated program using these manuals as the primary instructional material.

School administrators will be interested in the potential of these manuals to support a common first-year core of studies for two-year programs in such fields as: instrumentation, automation, mechanical design, or quality assurance. This form of *technical core* program has the advantage of reducing instructional costs without the corresponding decrease in holding power so frequently found in general core programs.

This manual, along with the others in the series, is the result of six years of research and development by the *Technical Education Research Centers, Inc.*, (TERC), a national nonprofit, public service corporation with headquarters in Cambridge, Massachusetts. It has undergone a number of revisions as a direct result of experience gained with students in technical schools and community colleges throughout the country.

Maurice W. Roney

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# The Electromechanical Series

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TERC is engaged in an on-going educational program in *Electromechanical Technology*. The following titles have been developed for this program:

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ELECTROMECHANISMS/DEVICES  
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For further information regarding the EMT program or for assistance in its implementation, contact:

*Technical Education Research Centers, Inc.  
44 Brattle Street  
Cambridge, Massachusetts 02138*

Technology, by its very nature, is a laboratory-oriented activity. As such, the laboratory portion of any technology program is vitally important. These materials are intended to provide a meaningful experience in fabrication techniques for students of modern technology.

The sequence of presentation chosen is by no means inflexible. It is expected that individual instructors may choose to use the materials in other than the given sequence.

The particular topics chosen for inclusion in this volume were selected to provide experience as near as possible to the industrial situation. Some instructors may wish to omit one of the exercises or to supplement some of them to better meet their local needs.

The materials are presented in an action oriented format combining many of the features normally found in a textbook with those usually associated with a laboratory manual. Each experiment contains:

1. An INTRODUCTION which identifies the topic to be examined and often includes a rationale for doing the exercise.
2. A DISCUSSION which presents the background, theory, or techniques needed to carry out the exercise.
3. A MATERIALS list which identifies all of the items needed in the laboratory experiment. (Items usually supplied by the student such as pencil and paper are normally not included in the lists.)
4. A PROCEDURE which presents step-by-step instructions for performing the experiment. In most instances the measurements are done before calculations so that all of the students can at least finish making the measurements before the laboratory period ends.
5. PROBLEMS are included for the purpose of reviewing and reinforcing the points covered in the exercise. The problems may be of the numerical solution type or simply questions about the exercise.



Students should be encouraged to study the textual material, perform the experiment, work the review problems, and submit a technical report on each topic. Following this pattern, the student can acquire an understanding of, and skill with, basic fabrication techniques that will be extremely valuable on the job.

The material on fabrication comprises one of a series of volumes prepared for technical students by the TERC EMT staff at Oklahoma State University, under the direction of D.S. Phillips and R.W. Tinnell. The principal author of these materials is Krishan Paul.

An **Instructor's Data Book** is available for use with this volume. Mr. Robert L. Gourley was responsible for testing the materials and compiling the instructor's data book for them. Other members of the TERC staff made valuable contributions in the form of criticisms, corrections, and suggestions.

It is sincerely hoped that this volume as well as the other volumes in this series, the instructor's data books, and the other supplementary materials will make the study of technology interesting and rewarding for both students and teachers.

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# experiment 1 NUMERICAL CONTROL OF MACHINE TOOLS

**INTRODUCTION.** This project should give the student an understanding of and experience in programming and operating a numerical control drill press.

**DISCUSSION.** Numerical control of machine tools is an area of automation which has been making steady progress for the last decade or so. Numerically-controlled machines are being used in all phases of engineering effort, from design to production. Wherever used, numerically-controlled machines increase accuracy, precision, and speed of operation.

Basically, all numerical control machines are comprised of two parts: the computer—which reads the coded instructions, interprets, and communicates them, and the machine tool—which executes the instructions. The instructions are generally punched on a one-inch-wide paper tape using some standard code. A magnetic tape is used in some applications, though the former is by far the most common type in use today.

The first step in using any machine is to study its features. Most machines currently being used for numerical tape control are point-to-point machines, though continuous-path features are also available. The instructions are stored on punched tape and fed to the controller through a tape reader. The controller interprets the instructions and directs the machine through the intended operations. Remember that a numerical control machine will do whatever it is programmed to do, and it will perform all the operations correctly *only* if the instructions are correct.

Feed control and the capability for drilling holes as well as milling are two other important features of this machine.

The table movement is only along two axes in the horizontal plane. (Other machines are available which have movement along other than horizontal planes.) The two motors used for moving the table are synchronized so that the table moves at a 45° angle in addition to its movement along the X axis and the Y axis. This limits the range and direction of continuous movement of the table. Milling along a continuous curve is not possible though holes can be drilled along the circumference of a circle or any other curvature. The following method should be used to plot the centers of holes along the circumference of a circle.

Suppose we are required to drill nine equidistant holes along the circumference of a circle three inches in diameter. Figure 1-1 shows the circle with the points. To determine the angular position of hole centers, we divide 360° by the number of holes, which in this case gives

$$\frac{360}{9} = 40^\circ$$

It can be seen that all the holes will be at an angular distance of 40° from each other. If one hole is located at A in Figure 1-1, the position of the other eight holes is given by B, C, D, E, F, G, H, and I. (It should be remembered that hole A can be located anywhere along the circumference and the positions of the rest of the holes will be located at an angular increments of 40° beginning at this point.) Also, for the sake of convenience, consider the center of the circle as the center

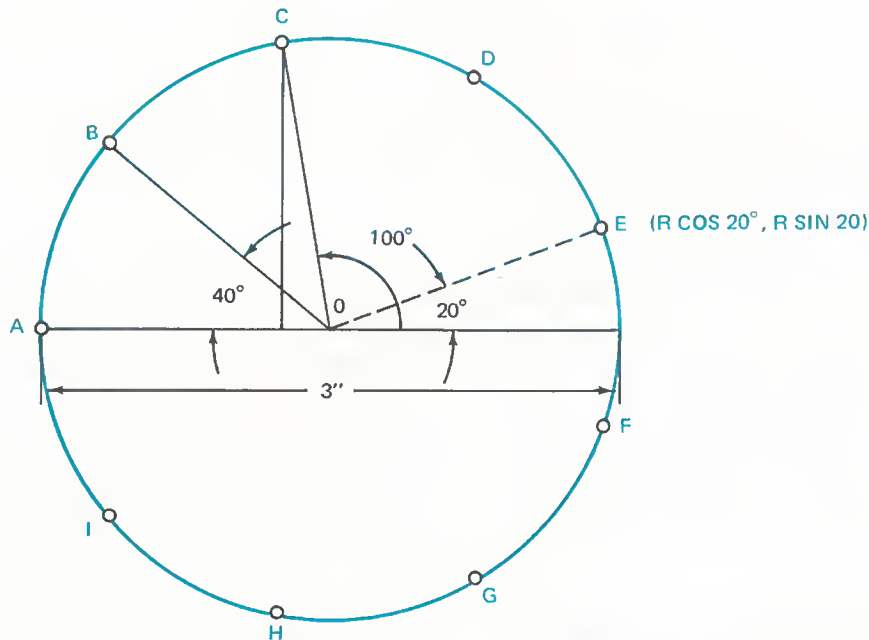


Fig. 1-1 Position of Nine Holes Along A Circle

of the X axis and Y axis; or in other words, the point (0, 0). Now point A is -1.5 in. from the center O so that it can be plotted as (-1.5, 0) with O as the origin and XX' and YY' as the horizontal and vertical axis respectively. Point E is 20° in angular distance from the horizontal axis in the positive (CCW) direction. The distance of point E from the X axis, therefore, is given by  $R \cos 20^\circ$ , or  $1.5 \times 0.940$  or 1.41 in. Similarly, the Y axis distance is  $R \sin 20^\circ$ , or  $1.5 \times 0.342$  or 0.513 in. Point E is then represented by (1.41, 0.513). Similarly, point D is given by  $(1.5 \cos 60^\circ, 1.5 \sin 60^\circ)$ , point C by  $(1.5 \cos 100^\circ, 1.5 \sin 100^\circ)$ , and so on. All nine points can be similarly plotted and programmed for drilling holes by choosing a suitable center.

After all the points are plotted and specifications are studied we are ready to write the program which can later be punched on tape and used by the machine to drill holes of the required size.

For *milling*, a *continuous* path has to be charted along which the tool will move. For this purpose, the points at the beginning and at the end of the milling operation need to be plotted. As already explained, numerical control machines allow movement along straight lines only and thus any shape of curves cannot be milled.

Before the machine can be programmed the following steps are important to note.

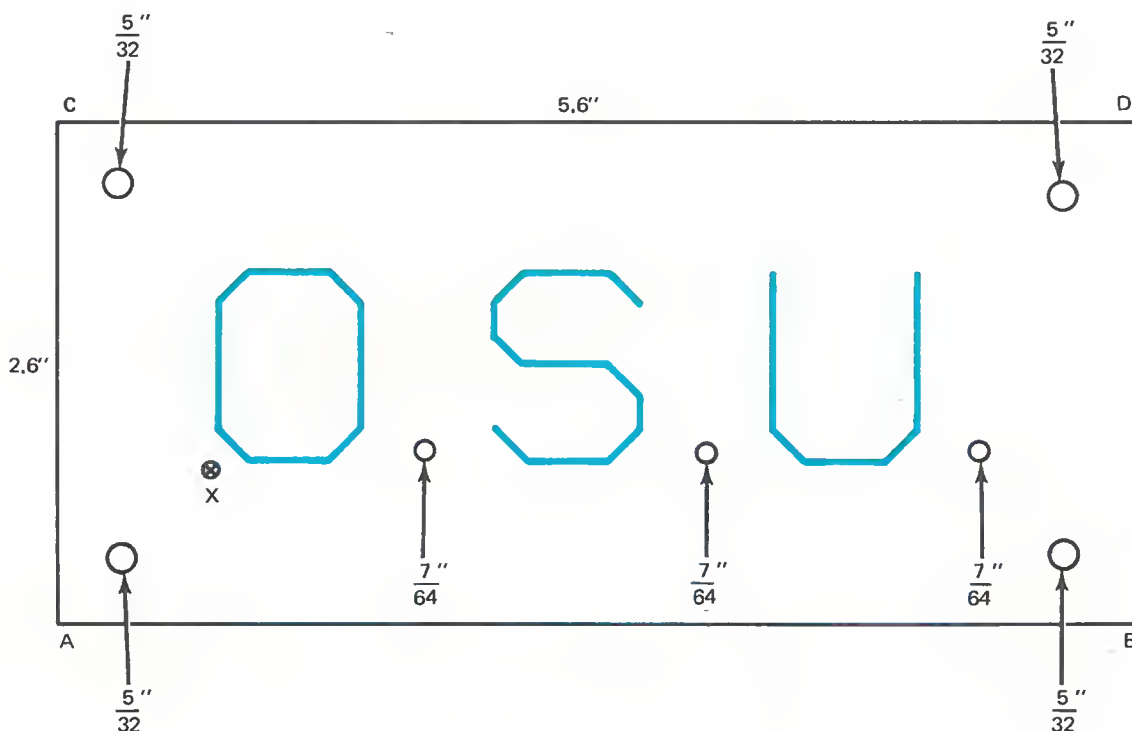
1. Prepare a detailed drawing showing the machining to be done, dimensions and position of holes, the tool path, and the positions of the fasteners required to hold the work on the table.
2. Determine the set-up point and the sequence of operations.
3. Determine the size and speed of the cutting tools.
4. Prepare a program sheet.

## MATERIALS

- |                                      |   |
|--------------------------------------|---|
| 1 Numerical control machine          | 1 1/16 in. milling tool                     |
| 1 Program punching machine with tape | 1 Brass plate, 5.6 in. X 2.6 in. X 3/16 in. |
| 1 Set of twist drills                | 1 Fine-cut file                             |

## PROCEDURE

Figure 1-2 shows the drawing of a piece (called a name plate) with specifications and the position of holes marked. The plate is 5.6 in. long and 2.6 in. wide. There will be four holes of 5/32 in. diameter in the four corners. The letters O, S, and U will be milled with a milling tool, making the letters 1/32 in. deep. The periods will be 7/64 in. holes drilled to a depth of 1/16 in.



*Fig. 1-2 Drawing of the Name Plate*

The set-up point will be a point X which is 0.8 in. from A B and 0.8 in. from A.C. The program sheet can be seen in Figure 1-3. The following M function codes have been used in programming for this project.

- 06 For tool change
- 52 For tool down for milling
- 53 For tool up
- 55 For high speed feed between the letters when the tool is up
- 02 For tape rewind

## NUMERICAL TAPE CONTROL PROGRAM

COMPANY NAME _____		ADDRESS _____	
PREPARED BY DATE	PART NAME	PART NO.	OPER. NO.
CK'D BY DATE	REMARKS:		
SHEET                      OF			
DEPT.			
TAPE NO.			

SEQ. NO.	TAB OR EOB	+ OR -	"X" INCREMENT	TAB OR EOB	+ OR -	"Y" INCREMENT	TAB OR EOB	"M" FUNCT.	EOB	INSTRUCTIONS
	EOB									
RWS	EOB									Tool hoses, 5/32 in. drill
1	TAB	-	0500	TAB	-	0500	EOB			
2	TAB			TAB		2000	EOB			
3	TAB		5000	EOB						
4	TAB			TAB	-	2000	TAB	06	EOB	Change drill to 7/64 and Adjust tool travel
5	TAB	-	0600	TAB		0600	EOB			
6	TAB	-	1400	EOB						
7	TAB	-	1400	EOB						
8	TAB	-	0900	TAB		0900	TAB	56	EOB	Change hoses to "auxiliary" Change tool for milling. Reduce feed speed and adjust tool travel
9	TAB			TAB			TAB	52	EOB	
10	TAB	-	0200	TAB	-	0200	EOB			
11	TAB			TAB	-	0600	EOB			
12	TAB		0200	TAB	-	0200	EOB			
13	TAB		0400	EOB						
14	TAB		0200	TAB		0200	EOB			
15	TAB			TAB		0600	EOB			
16	TAB	-	0200	TAB		0200	EOB			
17	TAB	-	0400	TAB			TAB	53	EOB	
18	TAB		1200	TAB	-	0700	TAB	55	EOB	
19	TAB			TAB			TAB	52	EOB	
20	TAB			TAB	-	0100	EOB			
21	TAB		0200	TAB	-	0200	EOB			
22	TAB		0400	EOB						
23	TAB		0200	TAB		0200	EOB			
24	TAB			TAB		0200	EOB			
25	TAB	-	0100	TAB		0100	EOB			
26	TAB	-	0600	EOB						

Fig. 1-3 Program for the "OSU" Name Plate

COMPANY NAME _____		ADDRESS _____	
PREPARED BY DATE	PART NAME	PART NO.	OPER. NO.
CK'0 BY DATE	REMARKS:		
SHEET                      OF			
DEPT.			
TAPE NO.			

[illegible]

5



1. Prepare the program sheets. Compare them with the program in figure 1-3.
2. Punch the program on the tape using the hand punching machine. (If there is a mistake, "delete" that particular sequence.) Punching of sequence numbers is optional and is for the sake of convenience only.
3. Mark the starting point of the tape with a pen. **It is easy to feed the tape from the other end and get completely wrong results.**
4. Mount the work on the table and with the positioning switch on manual, "job" the table to the "set-up" point.
5. Feed the tape into the reader, put the positioning and tool switches on "auto" and the feed switch on "high".
6. Start the reader and go through the program without the tool in position.
7. Notice and mark the position of the table at every tool operation cycle. (The use of a pencil in place of the tool with help mark the tool travel.)
8. Correct any mistakes in positioning or programming.
9. Mount the tool in the machine.
10. Start the tool (drill machine).
11. Start the reader.
12. Follow instructions in the programming sheet.
13. Compare with drawing from time to time.
14. At the end of the program switch off the tool and reader, remove the work, and remove the tool.
15. Clean and polish the work as necessary.
16. With a file, smooth all four edges and mount on a wooden block of suitable size.

Use *slow* feed rate (3 in. per minute) for *milling*, and 18 in. per minute or *high* feed for positioning and drilling. Do not forget to adjust the tool travel before milling and before drilling periods.

### PROBLEMS

1. Figure 1-4 shows a circle of 2 in. diameter with a point A at an angular distance of  $17^\circ$  from the horizontal axis. Plot the centers of ten equidistant holes to be drilled along the circumference of this circle, A being the center of the first hole.

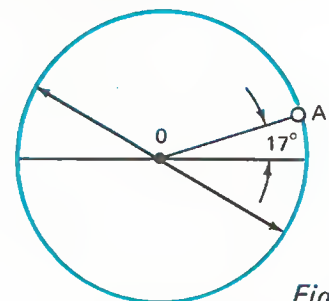


Fig. 1-4

2. Make a detailed drawing of the three initials on your own name. Write a program to mill the initials on a metal plate.
3. Discuss why you should use low speed for milling and high speed for positioning and drilling.

**INTRODUCTION.** This project is designed to enable the student to gain experience in operating machine tools, constructing miniature circuits, and testing and fitting different components.

**DISCUSSION.** Fabrication of components requires the use of many machine and hand tools. The most versatile and commonly used among these tools is the engine lathe. Besides turning metals, wood, and plastics, lathes can be used for drilling, boring, thread cutting, grinding, and milling. Though they differ in size and amount of sophistication, most lathes have some parts which are common to all designs and makes.

Remember, however, that the most important function of a lathe is the reshaping of metal parts by a turning operation. This basic function is performed by all lathes. All other possible operations like boring, grinding, and milling depend on the size and sophistication of a particular machine and, hence, on price. Figure 2-1 shows the common parts of a lathe.

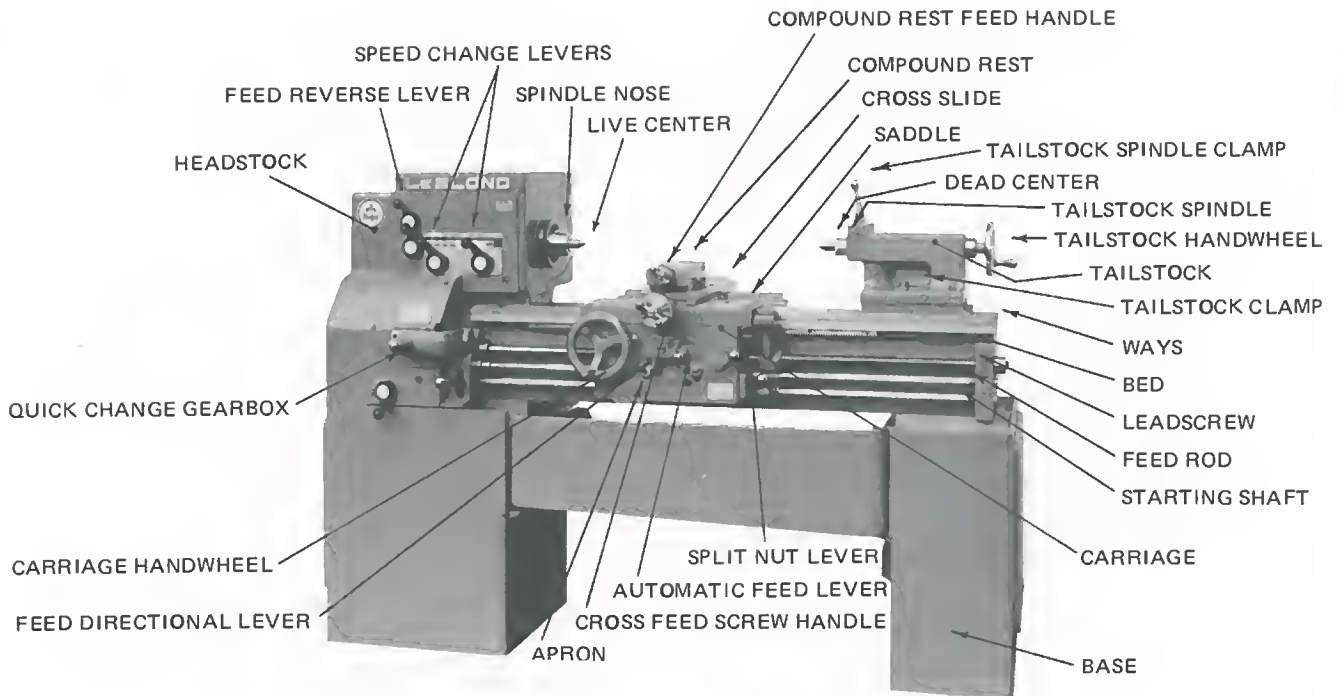
Knowledge of the controls and parts of the lathe as shown in Figure 2-1 is essential before starting work on one. Smaller machines generally have fewer features and can take only small pieces of work. (The size of a lathe is determined by the maximum size of work that can be turned.) The basic operations of turning and drilling, however, are standard on all lathes.

This project will require you to turn two metal components and one plastic component for the signal injector, besides drilling holes. Use of other hand tools will also be required for successful completion of the project. A thorough familiarity with the type of lathe you will work on is absolutely essential to produce quality work and avoid accidents.

### Safety

While working on or near machine tools it is very important that safety rules and precautions are strictly observed. Lathes, grinders and other machine tools can be very dangerous if improperly used. The following safety rules are suggested for enforcement in the laboratory or workshop.

1. Do not wear loose clothing. Ties must be tucked in, sleeves must be rolled up, and watches and rings must be taken off. If possible, wear an apron or shop coat.
2. Always wear safety glasses when working on lathes, drilling machines, or grinders.
3. Be familiar with the emergency stop control switch of all machine tools before starting work on them.
4. Follow instructions. The safest way to do a job is the correct way.
5. Do not roughhouse. Most accidents happen when you are off guard or careless. Do not try to hurry a job. Machines cannot work at more than their designed speed. Any undue rushing may end in unnecessary accidents.
6. Do not neglect small injuries. Cuts, burns, and scratches should be attended to immediately and dressed properly.
7. Keep your work area clean.



*Fig. 2-1 Engine Lathe*

Most of the accidents that happen in the laboratory or shop are due to either not following the safety rules or not knowing your machine well. You can help to cut down on accidents by following the rules yourself and requesting others to do the same. Be very familiar with the machine tool before starting work on it. Know all its features and capabilities, as well as its limitations.

### Taper Cutting

One of the many operations which is possible on a good lathe is called taper cutting. It is turning a round metal piece on a lathe in such a way that one end has a bigger diameter than the other end.

There are generally three methods of cutting tapers on engine lathes: (1) off-setting the

tail stock, thereby setting the lathe centers out of alignment; (2) using the taper-cutting attachment; and (3) setting the tool post (called compound rest on bigger and more expensive lathes) at an angle relative to the work. A brief outline of each of the three methods is given below.

1. Offsetting-the-lathe-centers method is used for taper cutting when the work is sufficiently long. The amount of set-over (or off-set) depends on the amount of taper and the length of the work. The following formula gives the amount of setover in inches.

$$\text{Setover} = \frac{\text{total length of work} \times (\text{large dia.} - \text{small dia.})}{2 \times (\text{length of taper portion})}$$

Note: All dimensions in inches.

When the centers are offset like this, the tool, which normally moves parallel to the bed of the lathe, cuts deeper towards the dead center than towards the live center, thus producing a taper. As the centers, when setover, do not bear fully into the ends of the work, the center holes tend to lose their true position after some usage. Because of this, this

method is not favored for precision work, especially if further operations are required to be done on the work subsequent to the taper cut.

2. The use of the taper attachment is another method of cutting tapers. This attachment fits on the lathe and is supplied with specifications and instructions for settings which depend on the amount of taper in inches per foot. The following formula gives the taper in inches per foot (t.i.p.f.).

$$\text{t.i.p.f.} = \frac{\text{larger dia. (in.)} - \text{smaller dia. (in.)}}{\text{length of the taper portion in inches}} \times 12$$

3. The same formula is used for setting the compound rest in the third method of cutting tapers. The compound rest is set at an angle given by the following equation.

$$\text{Angle} = \tan^{-1} \frac{\text{t.i.p.f.}}{24}$$

As the tool is fed in at an angle to the normal parallel movement, it turns the work into the predetermined amount of taper.

## MATERIALS

- |   |  |
|---|--|
| 1 Engine lathe, complete with three-jaw chuck and tool bits | 1 0-1 in. Micrometer                                       |
| 1 Set of twist drills                                       | 1 6-in. Steel rule   |
| 1 Set of hand tools   | 1 Outside caliper  |
| 1 File (fine cut)   | 1 Plastic rod, 1 in. long, 3/4 in. diameter                |
| 1 Bench vise  | 1 Pin jack   |
| 1 Soldering iron  | 2 Miniature ceramic disk capacitors, 0.04 $\mu$ F          |
| 1 Fine emery cloth  | 1 Miniature ceramic tubular capacitor, 100 PF              |
| 1 Aluminum tubing, 3-1/2 in. long, OD 5/8 in., ID 9/16 in.  | 2 Carbon resistors for base resistors, 22 kilohm, 1/2 watt |

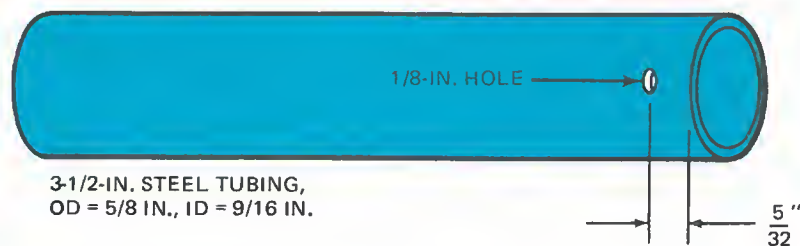


- |  |   |
|--|---|
| 1 Aluminum rod, 7/8 in. diameter,<br>1/2 in. long                    | 2 Carbon resistor for collector resistors,<br>470 ohm, 1/2 watt |
| 1 Brass rod, 5/16 in. diameter, 3/4 in. long                         | 2 Audio transistors   |
| 1 Steel coil spring, 1/4 in. long with<br>OD 1/4 in. and ID 3/16 in. | 1 Leakproof pen light battery, 1.5 volt                         |

## PROCEDURE

1. a) Hold the tube vertically in the bench vise with one end showing about one inch above the jaws. (A couple of small, wooden blocks with V-notches will help to provide a good grip.)
- b) Smooth the edges and remove burrs with a fine-cut file.
- c) Remove the tube and clamp it again with the other end above the jaws of the vise.
- d) Remove the tube from the vise and measure its length with a steel rule. The tube should be 3.5 in. long. If the length is more than 3.5 in., remove the excess metal with the file. Make several measurements to insure that the edges are true all around.
- e) Make a mark on the tube at a distance of 5/32 in. from one of the edges.
- f) Drill a 1/8-in. hole at the mark. (A V-block helps to keep the tube steady when drilling the hole.)

The finished tube is shown in Figure 2-2.



*Fig. 2-2 Finished Tube*

2. a) Hold the aluminum rod in the three-jaw chuck of the lathe with at least 3/8 in. protruding from the edge of the chuck. The three-jaw chuck is self-centering so not too much extra effort is required to center the work. If the work is not square, loosen the jaws, straighten the piece and tighten the jaws of the chuck again.
- b) Mount the round nose tool on the tool post and adjust its height to compare with the tail center of the lathe. **Remember, when working with aluminum, the height of the tool bits should be slightly higher than center to avoid chatter.**
- c) Start the motor and smooth the outer end of the aluminum rod with a slight cut.

- d) Turn the work to an outer diameter of  $\frac{5}{8}$  in. up to a length of  $\frac{7}{32}$  in. **Remember:**
1. Do not feed the tool in more than  $\frac{1}{32}$  in. for a single cut. A cut of  $\frac{1}{32}$  in. into a round piece reduces the diameter by  $\frac{1}{16}$  in.
  2. Take a measurement with the calipers after every cut.
  3. Take the final measurement with a micrometer.
- e) Mount the parting tool (ground to a width of  $\frac{1}{16}$  in.) on the tool post and adjust it at a right angle to the work. Slide it to a distance of  $\frac{5}{32}$  in. from the right edge of the work. Slowly feed the tool  $\frac{1}{16}$  in. into the work. Remove the tool and measure with the micrometer. The outer diameter of the work at this  $\frac{1}{16}$  in. groove should be  $\frac{1}{2}$  in.
- f) Mount the round nose tool back on the tool post and finish the diameter of the outer lip to  $\frac{19}{32}$  in.
- g) Remove the dead center from the tail stock and mount a drill chuck. Mount a  $\frac{3}{16}$  in. size drill bit into this chuck and drill a hole through the work piece.
- h) Mount a  $\frac{3}{8}$  in. drill bit in the chuck and drill a hole to a depth of  $\frac{1}{8}$  in. into the work piece.
- i) Remove the work and chuck the finished portion so that the other side can be machined.
- j) With the round-nosed tool, finish the overall diameter to  $\frac{5}{8}$  in.
- k) With the right hand finishing tool turn the face of the work to reduce the size to  $\frac{5}{32}$  in. between the groove and the edge.
- l) Chamfer the edge with a smooth file.
- m) With a  $\frac{5}{16}$  in. drill bit, drill a hole to a depth of  $\frac{7}{32}$  in.

The finished body of the switch can be seen in Figure 2-3.

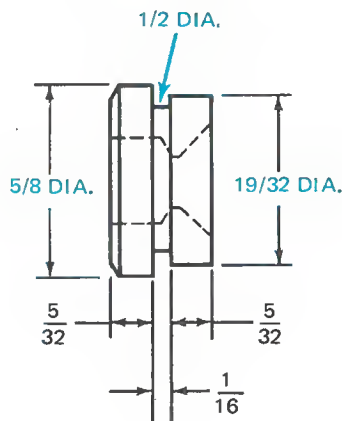
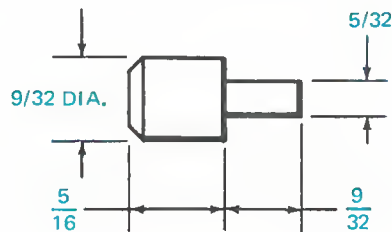


Fig. 2-3 Body of Switch

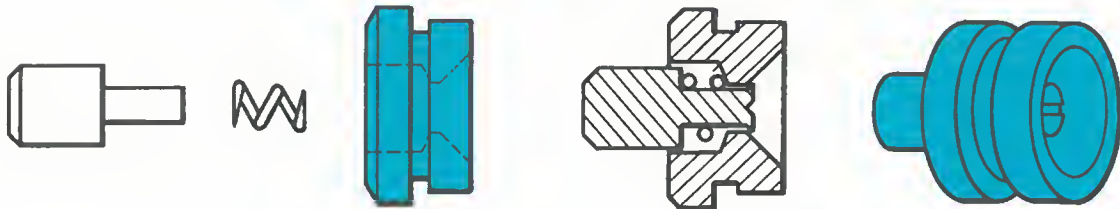


3. Hold the brass piece in the three-jaw chuck and machine it using the procedure outlined in step 2, according to the specification shown in Figure 2-4. With a 1/8 in. drill bit, drill a hole to a depth of 1/16 in. into the smaller end. Chamfer the larger edge.



*Fig. 2-4 Plunger for the Switch*

4. Assemble the switch as shown in Figure 2-5. With a centerpunch, flare the smaller edge of the plunger.



*Fig. 2-5 Assembly of Switch*

5. a) Hold the plastic round in three-jaw chuck so that about 5/8 in. extends from the edge of the jaws.  
 b) Mount a round-nosed tool on the tool post.  
 c) Reduce the speed of the lathe to between 500 and 600 RPM.  
 d) Turn the righthand face of the work.  
 e) Turn the work to reduce the diameter to 5/8 in. Take small (1/32 in.) cuts and measure with outside calipers after each cut.  
 f) Set the compound rest at an angle given by

$$\tan^{-1} \frac{(5/8 - 9/32) \times 12}{1/2 \times 24}$$

- g) Cut the taper so that the diameter of the right face is 9/32 in.  
 h) Remove the dead center from the tail stock and mount a 1/4-in. drill.  
 i) Drill a hole through the work with the 1/4-in. drill.  
 j) With 1/4 in. X 24 tap, thread the hole to a depth of 3/8 in.

- k) Remove the work from the chuck and hold it in the chuck with the other end ready to be machined.
  - l) With a round-nose tool turn the diameter to  $9/16$  in. up to the edge of the taper.
  - m) Turn the face of the work with the same tool to reduce the length between the edge of the taper and the face to  $1/4$  in.
  - n) Mount a  $7/16$ -in. drill bit to bore a hole into the work to a depth of  $7/16$  in.
  - o) Use a fine emery cloth to polish the work.
  - p) Remove the plastic work piece from the chuck.
  - q) Drill and tap a 4-40 hole on the collar of this plastic insulator at a distance of  $5/32$  in. from the edge of the taper. This hole should align with the hole drilled earlier in the tube.
6. a) Hold a standard pin jack in a bench vise with the sharp end held between the jaws.
- b) With a thread cutting die of  $1/4$  in. X 24 size, cut threads on the jack. (Use cutting oil for lubrication while cutting threads.)
- c) Apply a drop of solder on the end of the jack.
- d) Remove the jack from the vise and fit it into the insulator.

This completes the assembly of the probe which can be seen in Figure 2-6 below.

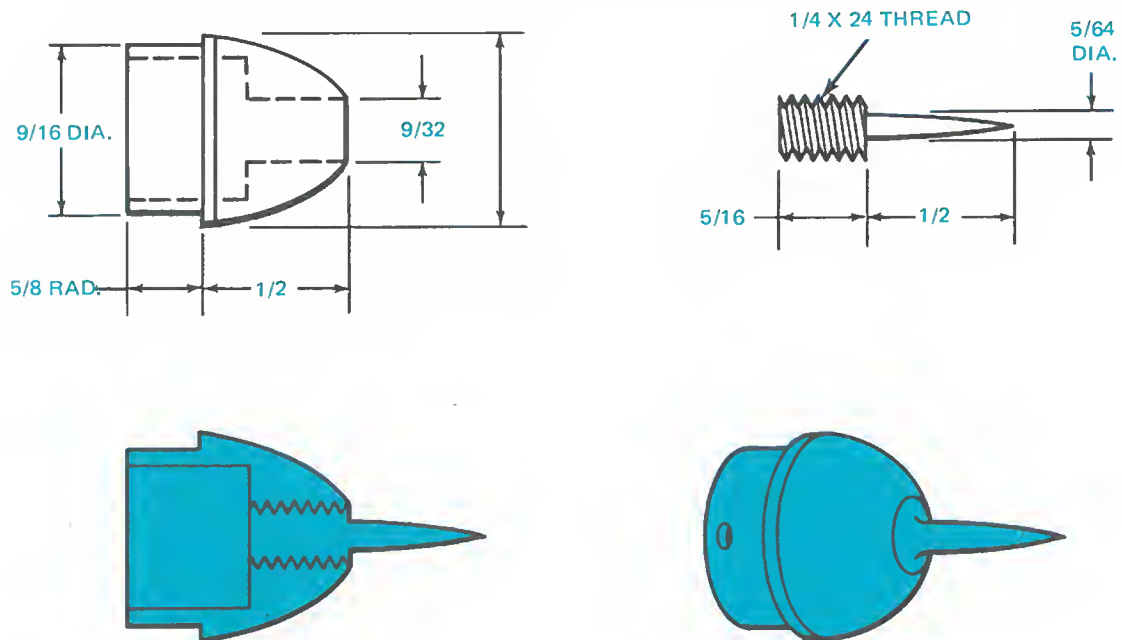


Fig. 2-6 Probe Assembly

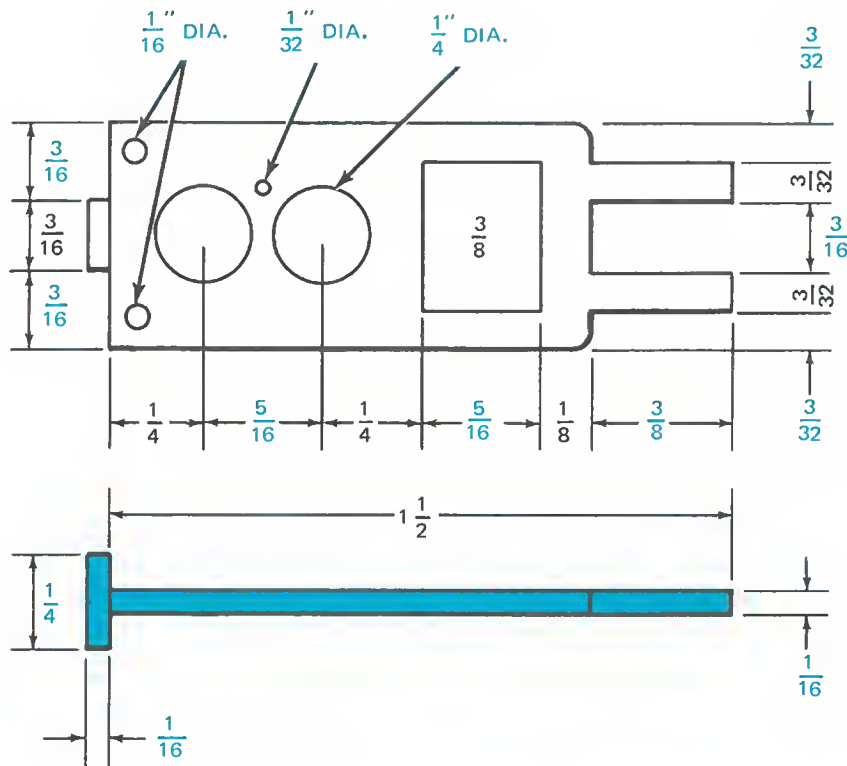


Fig. 2-7 Circuit Board Dimension

7. a). Take a piece of plastic circuit board and cut it according to the dimensions shown in Figure 2-7,
- b). Drill two  $\frac{1}{16}$ -in. diameter holes near the left hand corner as seen in Figure 2-7.
- c). Drill two  $\frac{1}{4}$ -in. diameter holes along the center line of the board as shown in Figure 2-7.
- d). Drill one  $\frac{1}{32}$ -in. hole between the  $\frac{1}{4}$ -in. holes as shown in Figure 2-7.
- e). Take a  $\frac{3}{16}$ -in. X  $\frac{1}{4}$ -in. X  $\frac{1}{16}$ -in. piece of sheet brass and glue it to the board (with epoxy glue). This piece will serve as a battery connector. See figure 2-7 for the position of the battery connector.

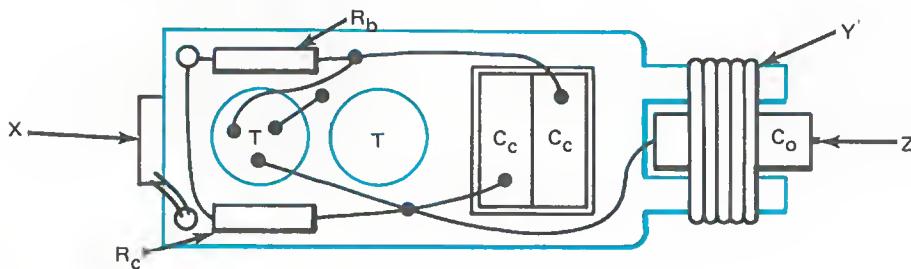


Fig. 2-8 Wiring of Circuit Board

- f) Mount the four resistors as shown in Figure 2-8. In each case run the rear lead through the corner holes. Solder these leads to the battery connector X on both sides of the board. In Figure 2-8,  $R_b$  and  $R_c$  represent the set of two resistors.
- g) Insert the transistors from each side of the board through the 1/4-in. holes as shown in Figure 2-8. Insert the emitter lead of the rear transistor through the 1/32-in. hole between the two transistors.
- h) Insert the two disk capacitors into the slot in front of the circuit board. Each capacitor should have one lead on each side of the board and should face each other.
- i) Solder the connector, transistor, capacitor and resistor leads as indicated in the wiring diagram in Figure 2-9.

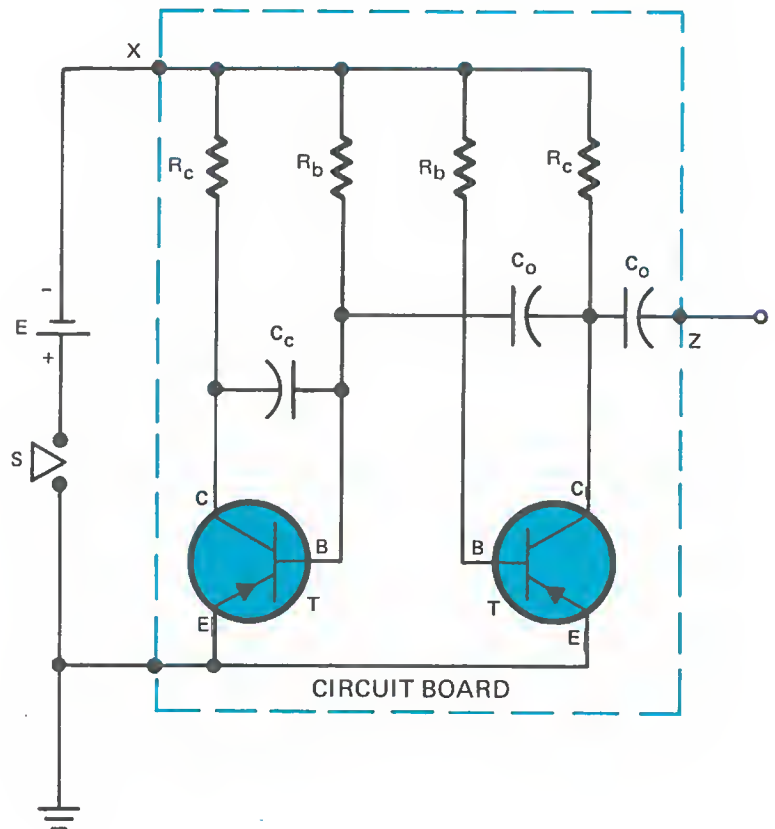
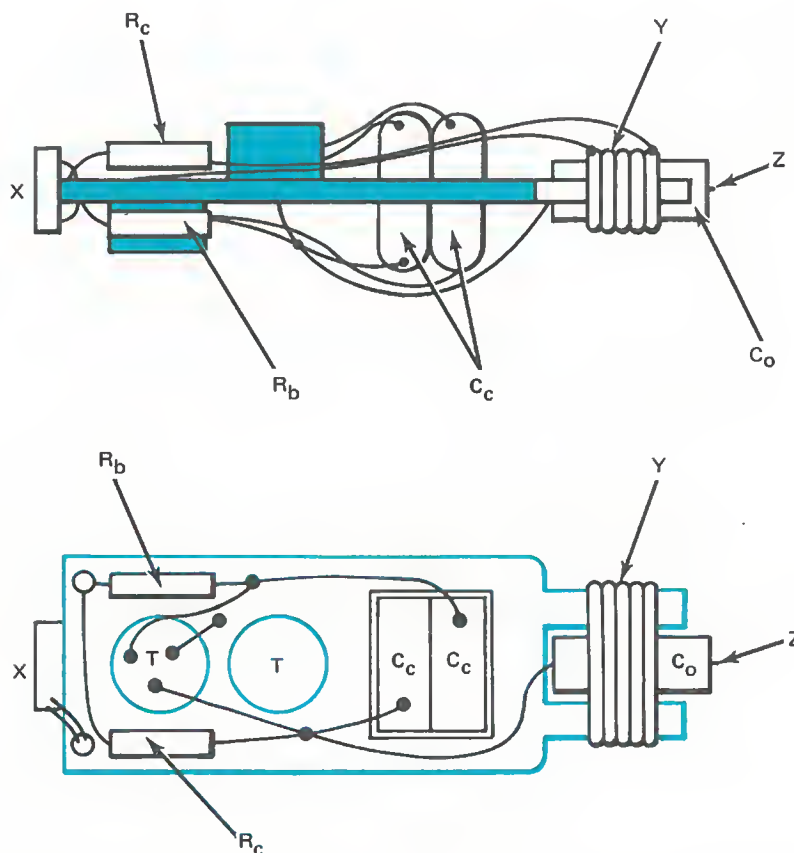


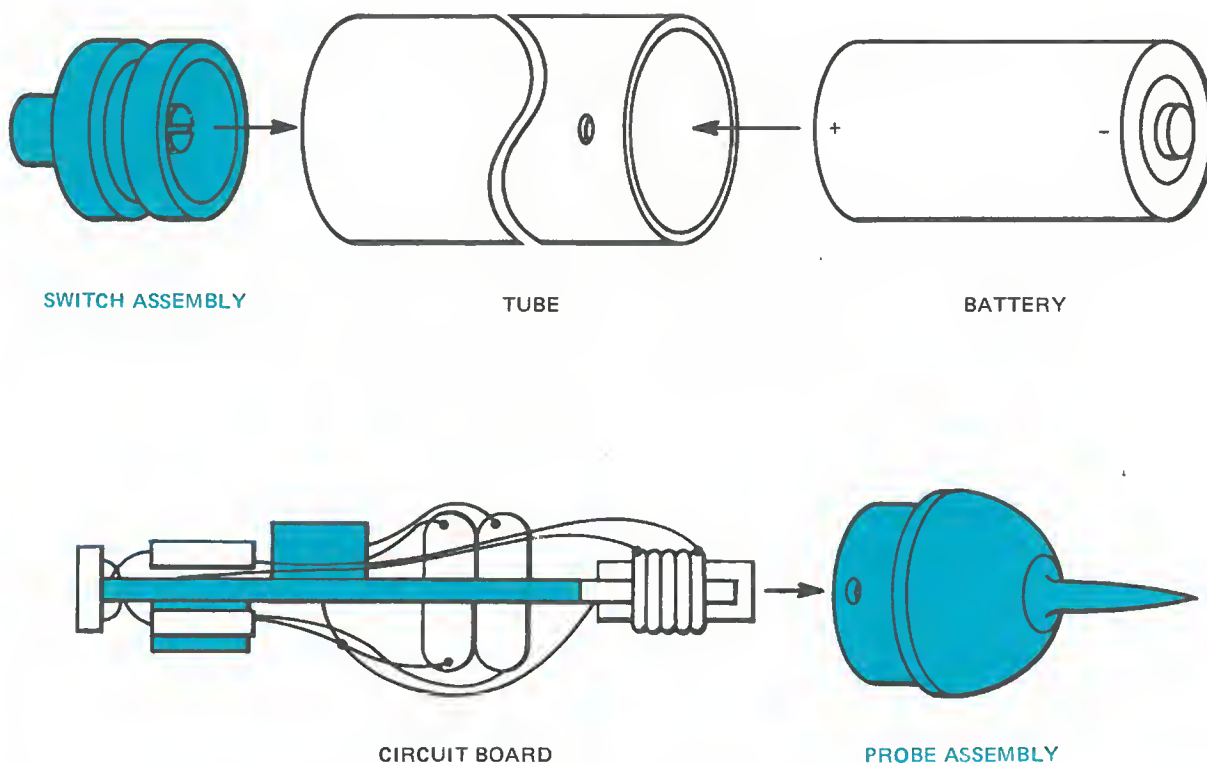
Fig. 2-9 Wiring Diagram

- j) Form the probe connector by making a loop with one lead of the tubular capacitor over its farther end. Put a drop of solder on the lead.
- k) Insert the capacitor and solder the remaining lead to a collector resistor.
- l) Form the common connector by wrapping several turns of number 20 tinned copper wire around the circuit board and tubular capacitor. This can be seen as Y in Figure 2-10.



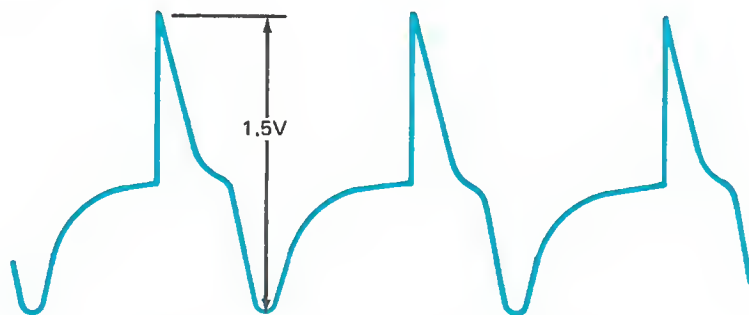
*Fig. 2-10 Front and Side View of the Circuit Board after Completion*

- m) Connect the emitter leads to the common connector using an insulated wire.
  - n) Check all the connections.
  - o) Check the completed circuit against Figure 2-1.
8. a) Press-fit the tube and the switch assembly. A difference of 1/32 in. in diameters should give a fairly good press fit. (Slight heat applied to the tube end which fits over the switch collar helps if there is not a good press fit.) Excessive pressure in making the press fit should be avoided, however.
- b) Insert the battery into the case with the positive terminal toward the switch assembly.
  - c) Insert the circuit board with the edge of the board aligned with the 1/8-in. hole in the tube.
  - d) Mount the probe assembly and align the hole on the collar with the hole on the tube.
  - e) Insert a number 4-40 X 1/8 in. long machine screw *only* far enough to secure the probe assembly to the tube.
  - f) Screw in the probe tip until the contents of the tube are tight.



*Fig. 2-11 Assembly Sequence of the Signal Injector*

- g) Tighten the machine screw until it makes contact with the common connector of the circuit board. Figure 2-11 shows the assembly sequence of the signal injector.
  - h) With a fine emery cloth clean and polish the assembly.
  - i) Test the signal injector.
9. a) Connect a wire from the case of the signal injector to the common connector of a cathode ray oscilloscope.
- b) Connect the probe tip of the signal injector to the vertical input of the oscilloscope.
- c) The waveform shown in Figure 2-12 should be viewed when the switch plunger is depressed.



*Fig. 2-12 Waveform of the Signal Injector*



**ANALYSIS GUIDE.** Fourier analysis of the waveform should be done to determine if the waveform produced by the injector matched the theoretical waveform. What are the factors which produce a different waveform?

### PROBLEMS

1. What changes in the circuit and/or in the procedures will be necessary if the transistor is changed from PNP to NPN?
2. What will be the resultant waveform as a result of changing the transistor from PNP to NPN?
3. Does the polarity of the battery affect the waveform?

# experiment 3 PREPROGRAMMED PLAYER ORGAN

**INTRODUCTION.** This project will provide an opportunity to the student to design and fabricate an electromechanical device; in particular, a device which will operate a player organ.

**DISCUSSION.** Design and fabrication are two of the important functions an electromechanical technician is called upon to perform. There are a number of projects which can be used for suitable classroom experience. The design and fabrication of a preprogrammed player organ described in this experiment is just one of those examples.

Unijunction relaxation oscillation can be called the *heart* of an organ tone generator. Figure 3-1 shows the circuit diagram of this oscillator with the waveforms at the emitter and across the resistors.

The emitter of the UJT possesses a high impedance as the capacitor  $C_E$  begins to charge through  $R_E$ . The charging rate of the capacitor is determined by the setting of  $R_E$  and the size of the capacitor itself.

Another factor involved in the rate of charge is the supply potential. The UJT possesses the characteristic of breaking into conduction when the voltage at the emitter reaches some predetermined value which is represented by  $V_p$  on the waveforms. (This voltage is usually around 3 volts.) As the supply potential begins to charge  $C_E$  through  $R_E$ , the firing level is reached, and the capacitor discharges its accumulated charge through  $R_{B1}$ , which is a relatively small resistor providing a quick discharge rate. Therefore, the voltage across the resistor  $R_{B1}$  is a set of spikes caused by the UJT breaking into conduction, and the capacitor discharging through the resistor. A sawtooth waveform occurs at the emitter of the UJT because this is actually the charge/discharge curve of the capacitor  $C_E$ . The voltage across  $C_E$ , therefore, appears as a sawtooth waveform, and this will be the waveform we will be concerned with in the tone generators.

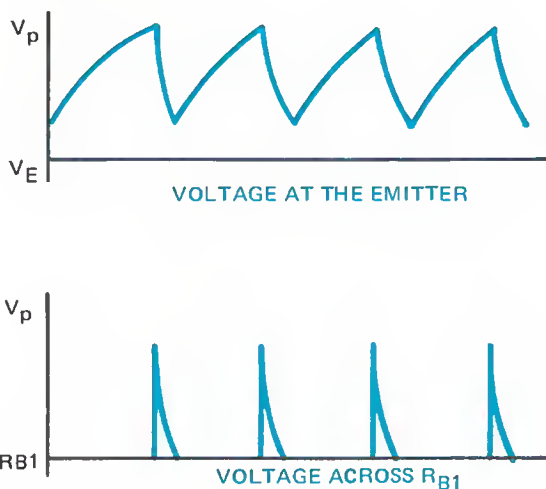
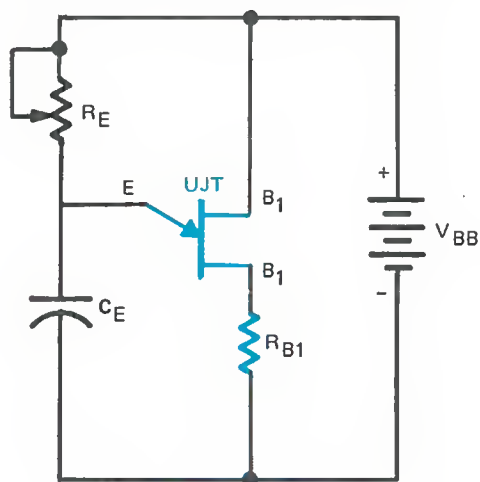


Figure 3-1 Circuit Diagram of Unijunction Transistor Relaxation Oscillator and Resultant Waveforms

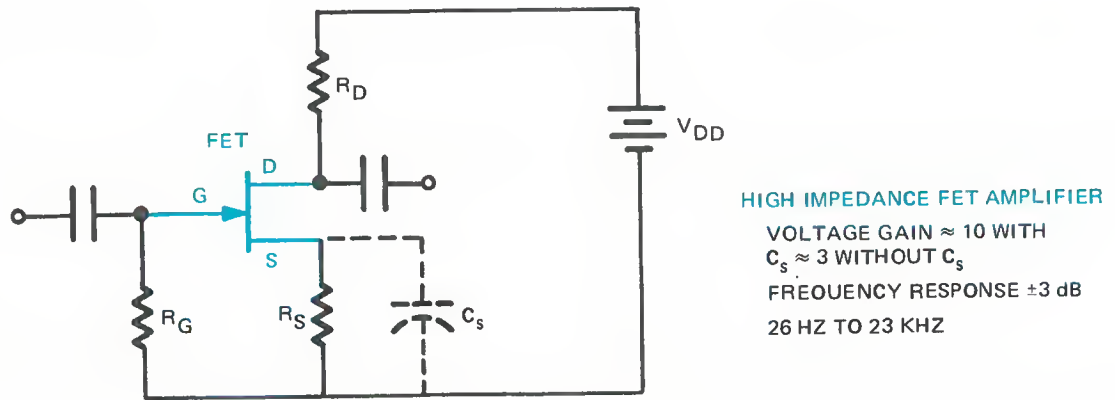


Fig. 3-2 Circuit Diagram of an FET Amplifier

The above tone oscillator must be fed into an amplifier. Figure 3-2 shows a simple one-stage field effect transistor (FET) amplifier.

Most amplifiers and tone-shaping circuits tend to load down the oscillator, causing the frequency of the oscillation to change or stop altogether. The FET is a very high impedance device and does not load the signal-creating device. Thus, it can be seen why a single FET amplifier stage is added to each oscillator. Looking at the diagram, we see that the signal is coupled to the gate of the FET by a small coupling capacitor. The gate is placed very near the ground potential by the gate leak resistor  $R_G$ . Bias of the stage is obtained by the source resistor  $R_S$  and the operation range

on the characteristic curves is set by the supply potential and the value of  $R_D$ . Some gain is lost by the biasing resistor  $R_S$  but can be retained by the addition of a source bypass capacitor  $C_S$ . This makes the gain of the stage approximately equal to ten. However, if one is not concerned with the gain of the stage but merely the high impedance coupling to the power amplifier, the bypass capacitor can be neglected and the gain of the stage can be stabilized. The frequency response of the stage is limited by the size of the coupling capacitors and the interelectrode capacitance of the FET.

Figure 3-3 shows the circuit diagram and the waveform of one of the tone generators.

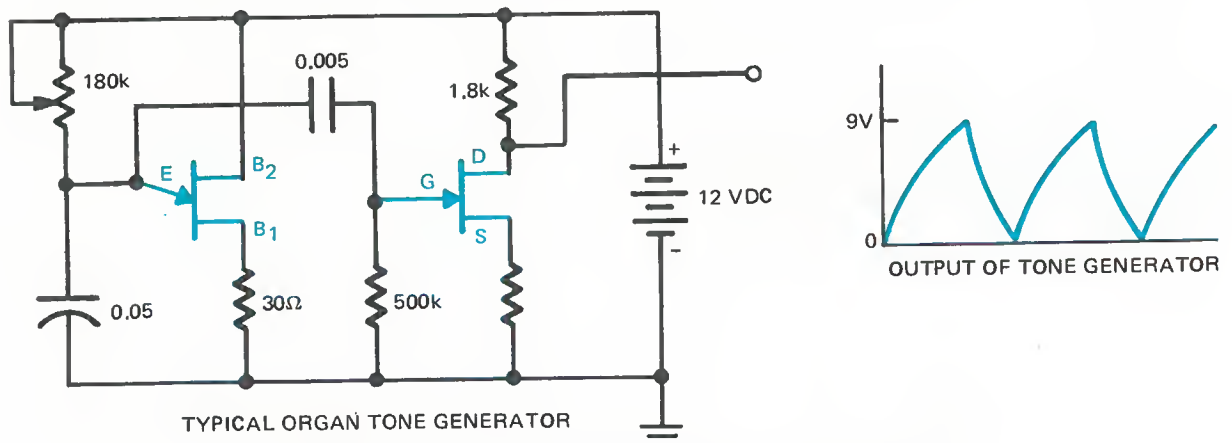


Fig. 3-3 Tone Generator and the Resultant Waveform

It can be seen that Figure 3-3 is a simple combination of the two previous circuits. The output waveform has an amplitude of approximately 9 volts peak-to-peak. The frequency is determined by the setting of the 180-kilohm potentiometer which can vary the range of the oscillator within two octaves. The organ consists mainly of a series of 25 of these tone generator circuits, each tuned to its respective frequency. Supply potential is derived from a power supply circuit which is zener-regulated to 12 volts. All the oscillators are

constantly in operation, and as a key of the player organ is depressed, the oscillator is connected to the power amplifier. If the power amplifier does not have an internal speaker, the output of the power amplifier should be connected to an external speaker.

Figure 3-4 shows how each oscillator is constantly in operation. When the note is to be played, it is simply connected to the power amplifier. The method of this connection is shown in Figure 3-5.

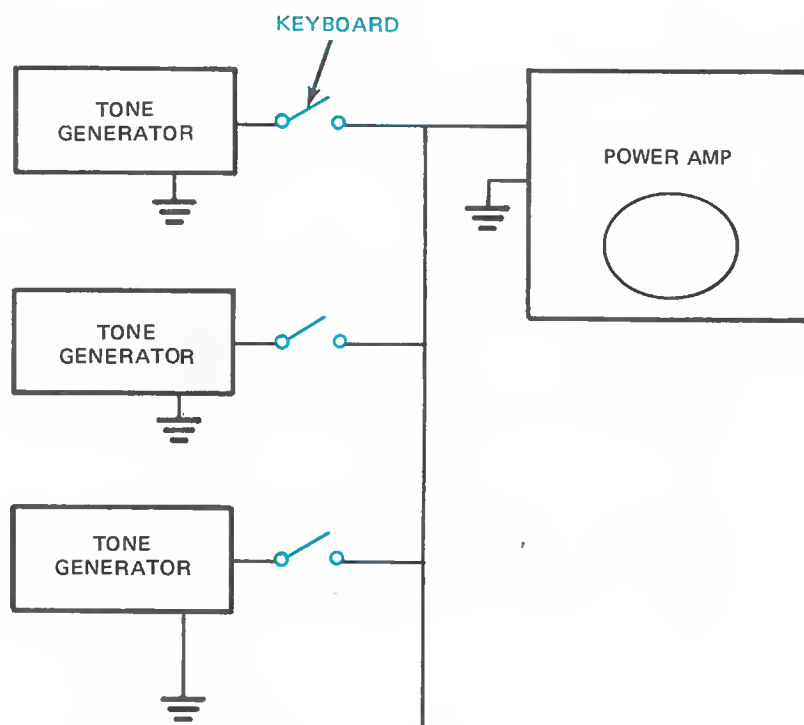


Fig. 3-4 Power Amplifier and Tone-Generator Connection Through Key Board

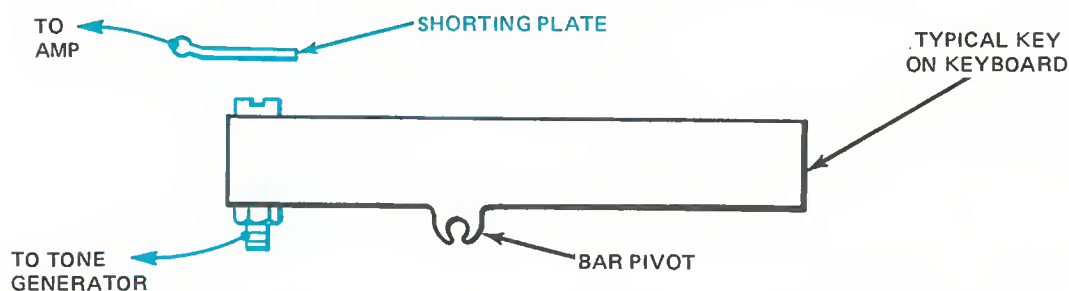


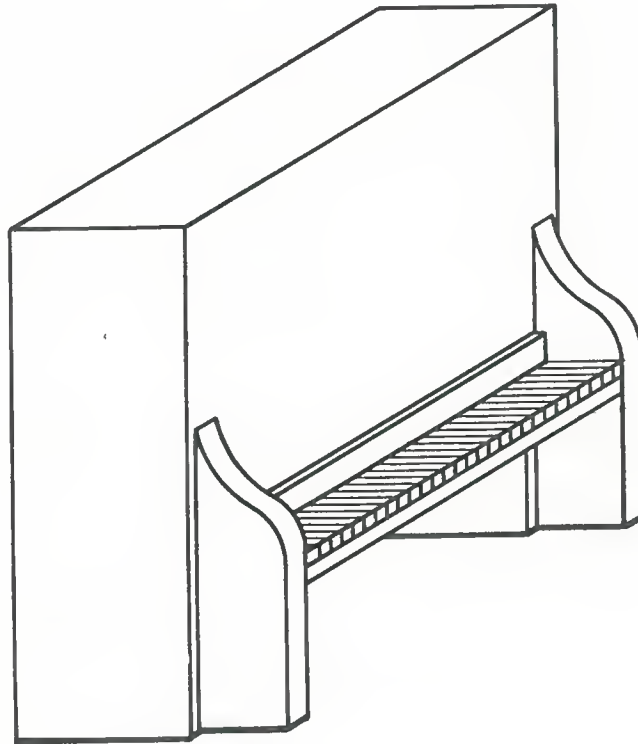
Fig. 3-5 Amplifier to Tone-Generator Connection Through Key Board

A long metal plate is placed above and to the rear of all the keys. This plate is connected to the input of the power amplifier. At the rear of each key is a screw which is connected to the respective individual tone generators. When the key is depressed, it connects this generator to the power amplifier. All the keys are on a pivot bar on which they rock. The keys return to their original position after playing due to the weight of the screw and a coil spring connected to the generators. These components are all housed in a small toy piano case. A drawing of the housing can be seen in Figure 3-6.

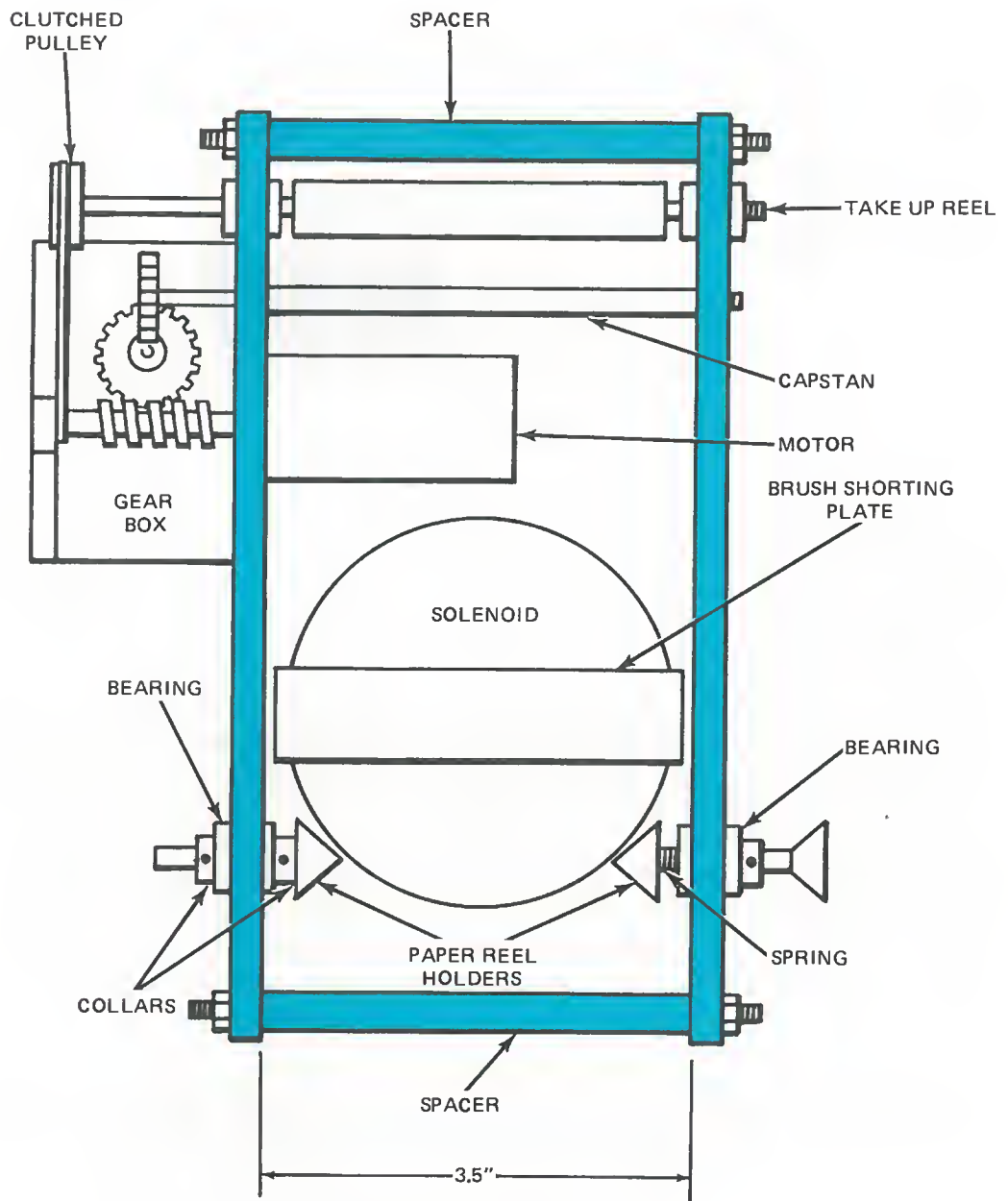
Contained within this case are the oscillators, power supply, and the switches. Connection to the power amplifier is made through a phone jack. Connection to the programming unit is made by a multipin jack.

The preprogramming unit is a gear train which drives a capstan and take-up reel as can be seen in Figure 3-7.

This capstan drives a sheet of paper over a metal plate on top of which is a set of steel wire brushes that short with the plate to complete the circuit when there is a corresponding hole in the paper. Each brush is connected back into the organ to an individual tone generator, and the shorting plate is connected to the input of the power amplifier. A gear train driven by a small DC motor turns the capstan. The total gear reduction of the double worm and wheel gear train is 625. This is derived by the fact that there are two gear reductions from a pair of 50-tooth wheels and a pair of thread worms. This gives a gear reduction of 25 per every set of worm and wheel. The re-



*Fig. 3-6 The Housing of a Player Organ*



*Fig. 3-7 Paper Tape Drive*

ductions are then multiplied, giving the resultant reduction of  $25 \times 25 = 625$ . The output of the gear train is directly coupled to the capstan, which determines the speed of the paper and keeps the paper moving at a constant rate. The paper is taken up on the take-up reel, which is turned by one of the faster shafts but is coupled in such a manner that it

slips to allow the capstan to determine the speed. This is done by a clutch-type mechanism that is constantly slipping. The reel of paper is placed between a pair of cone-shaped retainers which turn freely to allow the paper to come off the reel easily. One cone is spring-loaded to firmly hold the reel of paper while it is turning.



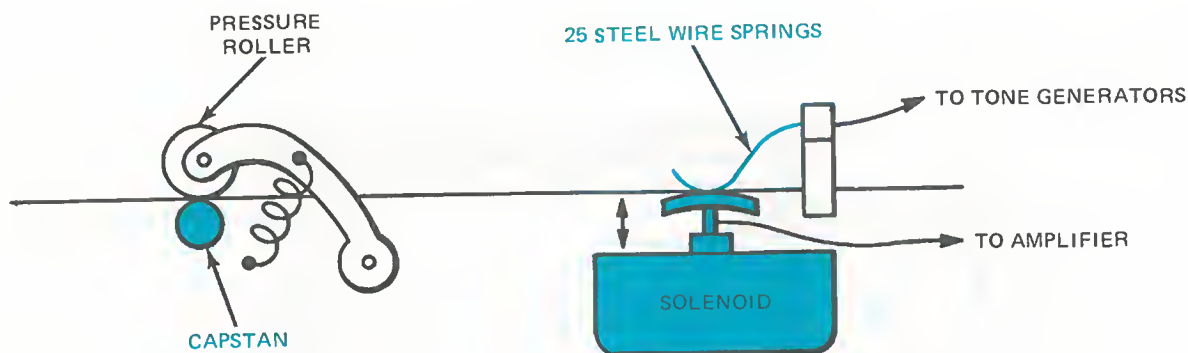


Fig. 3-8 Sideview of Tape Transport

Looking at Figure 3-8, we can see a couple of the drive components and their operations a little more closely. Here we see the steel wire brushes and their mounting. We also see the shorting plate on which the brushes make connection when meeting a hole in the paper. This shorting plate is connected to a solenoid which, when activated, pushes the plate up against the brushes. When the power is released from the solenoid, the shorting plate drops down away from the brushes. This makes it much easier to load or rewind the paper. This shorting plate is connected to the power amplifier through a shielded wire.

Also in Figure 3-8, the pressure roller for the capstan can be seen. This allows the cap-

stan to have constant pressure on the paper at all times. However, it can be moved back out of the way when loading paper, or when a fast forward or rewind speed is desired. The pressure roller tension is derived from a coil spring on either side of the roller fastened to the bearing plates holding firmly down against the capstan.

The paper tape is a regular 3-in. wide adding machine paper, which is easy to obtain and easy to program by punching rectangular holes at predetermined distances to create any desired note. Figure 3-9 shows a two-octave program punched in a section of the tape.

To make things a little simpler, the paper can be lined with two bars of musical staff

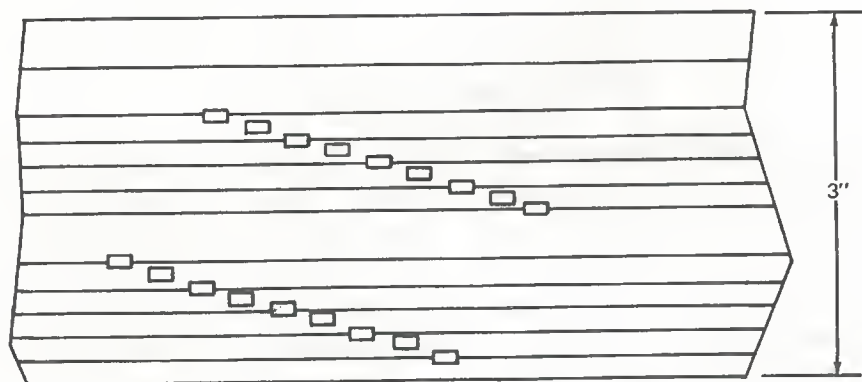


Fig. 3-9 Programmed Two-Octave Tape

and the holes will correspond to the particular note on the musical staff. The top line is kept for possible motor function programming.

It should be pointed out, however, that

other means of programming can be devised. An interesting mechanism could be a punched card program connected and transmitted through a computer.

## MATERIALS

NOTE: The number of components depends on the number of stages included in the design. Basically, the following components will be required for completion of the project. Exact numbers and specifications will be left to you to design.

Unijunction transistors  
FET  
Power supply  
Resistors  
Capacitors

Potentiometers  
Toy organ  
Gear train  
Program input device

## PROCEDURE

1. a) Design and fabricate a unijunction oscillator capable of producing the required frequencies. You may need more than one oscillator for different stages.
- b. Use printed circuit boards for the oscillators and tone generators. Figure 3-10 is a suggested layout for different tone generators. The number of units can be increased at will. The layout can also be changed with a change in design.

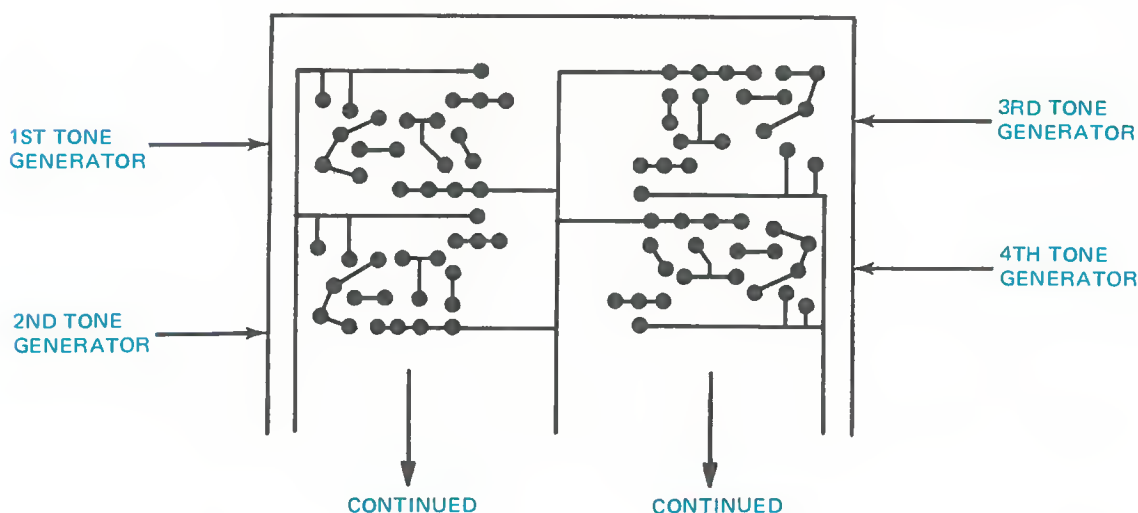


Fig. 3-10 Printed Circuit Board Layout

2. Design and fabricate an FET amplifier.
3. Hook up the amplifier to the toy organ and test the circuit.
4. Hook up the programming device and test it.
5. Program the player organ and test its overall operation.

### PROBLEMS

1. Diagram a similar system in which a stepping relay is used as a programming device.
2. How could the speed of the paper across the metal bar be varied if various musical tempos are desired.
3. What modification could be made so that the organ could be played manually in the conventional manner or programmed to play automatically?? Draw a circuit diagram of this modification.

Date: \_\_\_\_\_ Class \_\_\_\_\_ Instructor \_\_\_\_\_

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CK'D BY DATE	REMARKS:		
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*Fig. 1-3 Program for the "OSU" Name Plate*

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*Fig. 1-3 Program for the "OSU" Name Plate (Cont'd)*

EXPERIMENT 2 \_\_\_\_\_

Name \_\_\_\_\_

Date: \_\_\_\_\_

Class \_\_\_\_\_ Instructor \_\_\_\_\_





EXPERIMENT 3 \_\_\_\_\_ Name \_\_\_\_\_

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